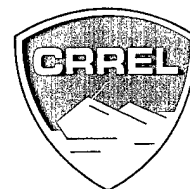


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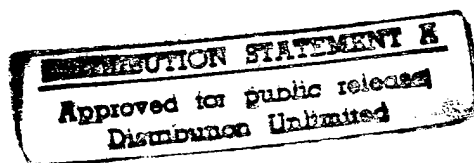
SPECIAL REPORT



The Effects of Temperature on Germination of Eleven *Festuca* Cultivars

Antonio J. Palazzo and Gurdarshan S. Brar

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Abstract: Many studies have shown that water potential at planting affects the germination rate and final germination of *Festuca* cultivars. Limited information is available about the extent of variability in temperature-dependence of germination among different *Festuca* cultivars. Our objective was to study germination at five temperatures for a wide range of *Festuca* cultivars. *Festuca* seeds were screened for germination during 28 days in polyethylene growth pouches held at constant temperatures of 10, 15, 20, 25, or 30°C. The germination percentage significantly ($p < 0.05$) increased as the temperature increased from 10 to 15°C, when averaged across the cultivars, and decreased thereafter. The cultivar "Clemfine" tall fescue (*Festuca arundinacea* Schreb.) had the greatest germination percentage, and "Arctared" red fescue (*Festuca rubra* L.) had the least when averaged across the five temperatures. Conversely, the average time to germination (A_{tg}) was greatest at 10°C and least at 30°C. Reaching a germination level of 80% or more of the seeds required 14 days at 10°C, 9 d at 15°C, 8 d at 20°C, and 7 d at 25 or 30°C. Base

temperatures required for germination of *Festuca* species were 3.2°C for rapid germinators, 3.6 to 6°C for medium germinators, and 4 to 6°C for poor germinators. Heat units (growing degree-days $>10^{\circ}\text{C}$) calculated for the rapid germinators were 129°C-d, 120 to 140°C-d for medium germinators, and 135 to 191°C-d for the poor germinators. Germination decreased as heat units were increased. The A_{tg} and heat unit regressions explained 91% and 66% of the variations in germination, respectively. The optimum temperature for germination of *Festuca* cultivars was 15°C. Seeding time for some *Festuca* cultivars could be varied based on expected seed zone temperatures for particular locations. Results of this study should be interpreted with caution, but they suggest that selection for rapid growth rate among materials of favored phenological patterns may lead to improved establishment of faster species on poorly managed sandy soils in cold climates. Rapidity and total germination are the most obvious factors distinguishing *Festuca* cultivars. This study demonstrates the variability in cultivar germination in response to temperature.

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PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, and Gurdarshan S. Brar, Research Physical Scientist, Geochemical Sciences Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

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The Effects of Temperature on Germination of Eleven *Festuca* Cultivars

ANTONIO J. PALAZZO AND GURDARSHAN S. BRAR

INTRODUCTION

Once established, hard fescues (*Festuca* sp.) can survive for many years on military training lands consisting of sandy soils (Palazzo 1994). Major constraints of *Festuca* establishment are lack of sufficient water in the seed zone, variation in seed zone temperature at planting, and harsh environmental conditions. The period between planting and seedling emergence comprises two distinct temperature-dependent phases: seed germination and preemergence seedling growth (Wheeler and Ellis 1991). Selecting *Festuca* cultivars for rapid and uniform germination under a wide range of temperatures would seem to be important for early seedling establishment. The cultivars that germinate quickly might be capable of rapidly developing a root system that would move ahead of the drying soil front.

A broad classification of grasses based on optimum temperature coincides with their separation into photosynthetic pathway types: cool-season grasses represent the C3 pathway, and warm-season grasses use the C4 photosynthetic pathway (Gould and Shaw 1983). Compared with C3-type plants, C4 species are more resistant to drought (Doliner and Joliffe 1979); however, it is unclear if this analogy extends to the germination and seedling stages. Total germination and germination rates of cool-season and warm-season grasses were significantly influenced by the interaction of temperature and water stresses (Qi and Redmann 1993). High and low temperature extremes increased the sensitivity of germination rate to moisture stress and decreased the germination percentage.

The importance of germination rate in the

establishment of annual grasses has been reported in the literature (Derwyn et al. 1966, Smith 1968). The germination rate, defined as the reciprocal of the time taken for half the population to germinate, usually increases linearly with temperature, at least within a well-defined range (Hegarty 1973, Bierhuizen and Wagenvoort 1974, Thompson and Fox 1976).

Selecting *Festuca* cultivars for rapid and uniform germination under a wide range of temperatures is important for early seedling establishment in the field (Brar and Stewart 1994). Temperature affects germination of grass seeds, with varying responses among species (McWilliam et al. 1970). Slow germination and low seedling vigor limit the establishment of perennial warm-season forage grasses, and temperature is a major environmental factor influencing both processes (Hsu et al. 1985).

Little information is available about environmental influences on germination and the extent of variability in germination at various temperatures for different *Festuca* cultivars. Therefore, our objective was to study the effect of five temperatures on the germination percentage for a wide range of *Festuca* cultivars.

MATERIALS AND METHODS

Festuca germination experiments were conducted in a growth chamber at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Eleven *Festuca* cultivars (Table 1) were evaluated for germination under various temperatures by a growth pouch technique (Brar et al. 1991). *Festuca* seeds were obtained from a

Table 1. *Festuca* cultivars tested for germination at various temperatures.

Cultivars	Scientific name	Common name
Jamestown, Victory	<i>Festuca rubra</i> var. <i>commutata</i> Gaud.	Chewings fescue (CF)
Cindy, Dawson	<i>Festuca rubra</i> L.	Creeping red fescue (CRF)
Spartan, Reliant	<i>Festuca ovina</i> var. <i>duriuscula</i> (L.) Koch.	Hard fescue (HF)
Arctared, Jasper	<i>Festuca rubra</i> L.	Red fescue (RF)
Azay	<i>Festuca ovina</i> L.	Sheeps fescue (SF)
Clemfine, Tribute	<i>Festuca arundinacea</i> Schreb.	Tall fescue (TF)

commercial source in New Jersey. Seeds (50) of each cultivar were selected at random and placed in growth pouches. The growth pouches were placed in the germination chamber for six weeks at constant temperatures of 10, 15, 20, 25, or 30°C and 75% relative humidity. Germination counts were recorded daily. Seed germination was determined by radicle protrusion through the seed coat, in accordance with the Association of Official Seed Analysts (AOSA 1970) definition of seed germination.

The germination percentages at 28 days after imbibing were calculated from the total number of seeds germinated at each temperature divided by the total number of seeds used for each cultivar. The weighted mean germination time (Heydecker 1966, Brar and Stewart 1994) or average time to germination (A_{tg} in days) was calculated as

$$A_{tg} = \sum \left(\frac{n \times d}{N} \right) \quad (1)$$

where n is the number of seedlings germinated on day d , and N is the total number of seedlings germinated.

A linear regression model proposed by Angus et al. (1981) was used to estimate the threshold temperature for germination:

$$A_{tg}^{-1} = b_0 + b_1 T \quad (2)$$

where T is temperature, and b_0 and b_1 are the regression constants. Threshold temperature (T_b) was estimated as

$$T_b = \frac{b_0}{b_1} \quad (3)$$

The heat units (HU) (growing days >10°C) were calculated as

$$HU = (T - T_b) A_{tg} \quad (4)$$

The experimental design was considered as a series of experiments repeated four times over temperature with replications nested within temperature as described by Kempthorne (1952). Within each temperature treatment (germination chamber), the design was a randomized complete block. Separate analyses of variance were structured for germination and average time to germination.

RESULTS AND DISCUSSION

A pooled analysis of variance indicated that cultivar and temperature treatments had a significant effect on the mean germination and average time to germination of *Festuca* sp. (Table 2). The cultivar \times temperature interactions were also significant ($p < 0.001$) for germination and A_{tg} . This study supports the findings of other workers for forage legumes (Brar et al. 1991), sorghum (Brar and Stewart 1994), and warm-season forage grasses (Hsu et al. 1985).

Table 2. Analysis of variance for laboratory germination and average time to germination (A_{tg}) of 11 *Festuca* cultivars.

Source of variance	df	Mean squares	
		Germination	A_{tg}
Cultivars (C)	10	10477*	88*
Temperature (T)	4	94*	610*
C \times T	40	566*	8*
Error	165	39	0.7

* Significant at $p = 0.001$ probability level.

Germination percentage averaged across all cultivars significantly ($p < 0.05$) increased as temperature increased, from 71% at 10°C to 80% at 15°C (Table 3). Germination percentage declined above 15°C and remained nearly constant as the temperature increased to 30°C. Cultivars were grouped into three categories based on mean germination performance across temperature treatments: rapid, with germination above 90%; moderate, with germination between 80% and 90%; and slow, where germination was less than 80% (Brar and Stewart 1994). Among the cultivars tested across all temperatures, one was rapid, six were moderate, and four were slow

Table 3. Mean final germination percentage of *Festuca* cultivars as influenced by temperature at 28 days.

Cultivar	Germination (%)						Cultivar	Germination (%)					
	10°C	15°C	20°C	25°C	30°C	Mean		10°C	15°C	20°C	25°C	30°C	Mean
Jasper	89	93	87	93	86	89	Victory	81	66	69	75	76	73
Clemfine	94	94	88	89	96	93	Cindy	92	92	55	43	27	60
Jamestown	94	92	83	88	77	86	Dawson	57	66	74	72	70	68
Reliant	78	87	92	87	95	88	Arctared	0	15	14	17	14	12
Azay	57	97	87	87	93	84	LSD* (0.05)	11	7	11	11	8	4
Spartan	79	88	77	83	72	80	Mean	71	80	73	74	72	
Tribute	64	91	84	84	90	82	LSD (0.05) = 3						

* Least-square differences at $p < 0.05$ according to Student-Newman-Keuls test.

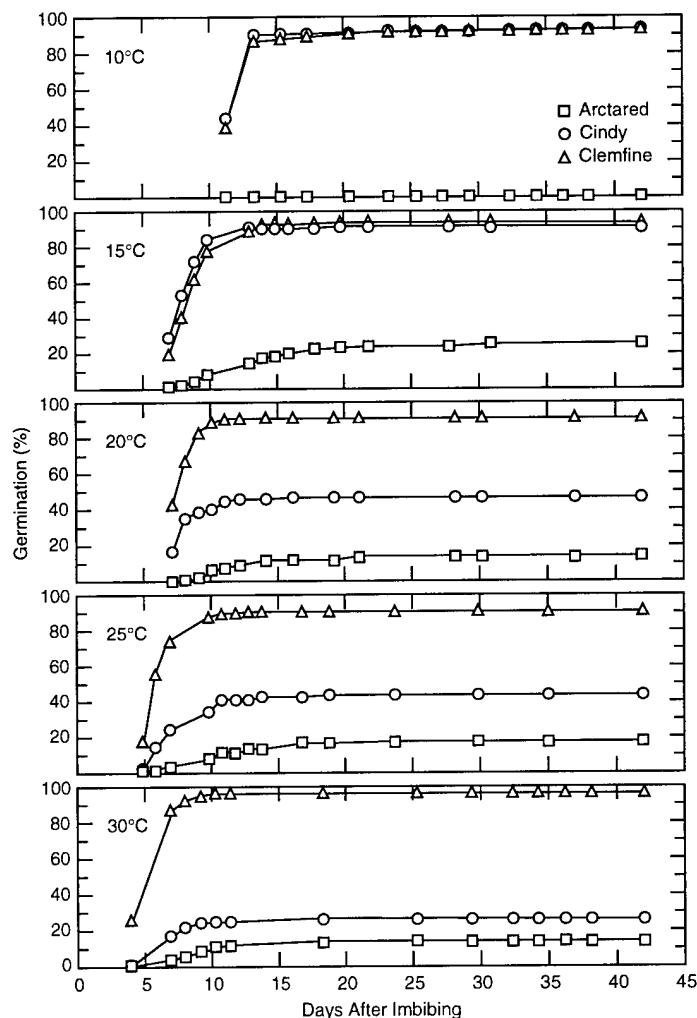


Figure 1. Germination trends for *Festuca* cultivars as influenced by temperature and time after imbibing.

germinators (Table 3). Clemfine TF had the greatest germination percentage, followed by Jasper RF. The lowest germination percentage was recorded for Arctared RF.

Cultivars that germinate over a relatively wide range of temperatures may be easier to establish

in the field than those with a highly specific temperature requirement. Clemfine TF was most vigorous in germination among all the cultivars evaluated because it exhibited the highest germination percentage over a broad range of temperatures. Brar and Palazzo (1995a) reported that Clemfine TF had more rapid root development, grew faster, and transpired more water than Reliant HF. Cultivars Cindy CRF and Victory CF are temperature-specific and performed well at lower temperatures. The cultivars Reliant HF, Azay SF, and Tribute TF were poor germinators at 10°C but performed better between 15° and 30°C.

Germination time response curves for Arctared RF, Cindy CRF, and Clemfine TF at all the temperatures studied revealed the magnitude of interactions between cultivars and indicated that temperature strongly influenced germination (Fig. 1). At 10°C, Clemfine TF and Cindy CRF had their greatest germination percentage within 11 to 13 days. However, Arctared did not germinate at 10°C. At 15°C, again Clemfine and Cindy reached >80% germination at 10 d, while at the same time Arctared had 9% germination. Similarly, Clemfine exceeded 80% germination by 9 d at 20°C, 7 d at 25°C, and 6 d at 30°C. Conversely, Cindy and Arctared failed to reach even 60% germination at higher temperatures. In regions where lower temperatures exist at planting, rapidly germinating cultivars such as Clemfine TF, Jamestown CF, and Jasper RF may be best (Table 3). In addition, an early high germination rate may allow rapid establishment on poorer sandy soils where the

Table 4. Average time to germination (A_{tg} in days) of *Festuca* cultivars as influenced by temperature.

Cultivar	A_{tg}					Mean
	10°C	15°C	20°C	25°C	30°C	
Jasper	13.4	9.2	7.6	6.4	6.8	8.7
Clemfine	12.5	9.3	8.0	6.8	6.3	8.6
Jamestown	13.3	8.6	8.9	6.8	8.6	9.0
Reliant	13.5	8.6	8.5	6.5	6.8	8.8
Azay	14.8	10.0	7.9	7.4	7.3	9.5
Spartan	15.5	8.9	8.2	6.3	7.2	9.3
Tribute	14.1	9.8	8.0	6.9	6.6	9.1
Victory	14.6	9.9	8.9	8.5	7.2	9.8
Cindy	12.4	9.0	8.5	8.2	8.6	9.3
Dawson	14.4	10.8	8.5	8.6	7.5	9.9
Arctared	25.0	14.2	12.1	11.7	10.5	14.7
LSD* (0.05)	1.1	1.3	1.4	1.1	1.0	0.5
Mean	14.9	9.9	8.6	7.6	7.5	

LSD (0.05) = 0.3
 * Least-square differences at <0.05 according to Student-Newman-Keuls test.

water content in the upper soil surface is only available for a short time. Brar and Palazzo (1995b) emphasized that screening of turfgrass for rapid root development is important for both quicker establishment and long-term persistence for disturbed soils and adverse climatic conditions.

Average time to germination decreased as temperature increased from 10 to 15°C (Table 4). The mean A_{tg} was greatest at 10°C and lowest at 30°C. Clemfine and Jasper were among the cultivars with lowest A_{tg} at each temperature. The poor germinator (Arctared RF) had a greater A_{tg} than the other 10 cultivars. For 80% or more of the seeds to germinate required an A_{tg} of 14 d at 10°C, 9 d at 15°C, 8 d at 20°C, and 7 d at 25 or 30°C.

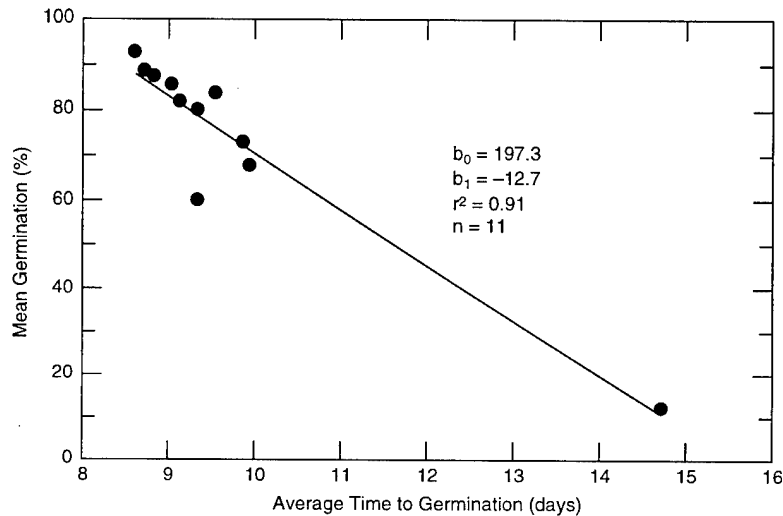


Figure 2. Relationship of mean germination and average time to germination.

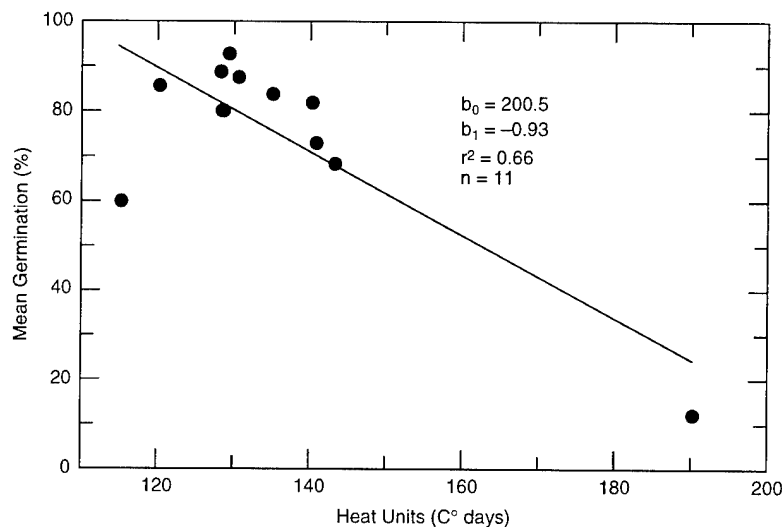


Figure 3. Relationship of mean germination and heat units.

Base temperatures required for germination of *Festuca* species were 3.2°C for rapid germinators, 3.6 to 6°C for medium germinators, and 4 to 6°C for poor germinators. Heat units (HU) (growing degree-days >10°C) calculated for the rapid germinator were 129°C-d, 120 to 140°C-d for medium germinators, and 135 to 191°C-d for the poor germinators. Radford and Henzell (1990) reported that differences among sorghum genotypes for germination were due to differences in base temperature. Furthermore, they speculated that any genotype with a high base temperature might have insufficient time to complete elongation of radiate protrusion through the seed coat and subsequently fail to germinate.

The mean germination of *Festuca* cultivars was significantly ($p < 0.05$) regressed with mean A_{tg} (Fig. 2) and heat units (Fig. 3). Germination decreased as A_{tg} and HU increased. The A_{tg} and HU regressions explained 91% and 66% of the variation in germination, respectively.

Cultivars that germinated rapidly had lower HU and A_{tg} values, so they have the chance to establish in the field earlier than medium and slow germinators (Brar and Stewart 1994).

Rapid and total germination are the most obvious factors distinguishing the cultivars used in this study. The two TFs (Clemfine and Tribute) as a group had a greater total and rate of germination than the other five species. Palazzo and Brar (1997) screened *Festuca* cultivars for rapid root development and reported that Clemfine TF had the deepest root system and greatest cumulative root elongation rates among the 12 cultivars used in the test. The rate of germination increased linearly with temperature from a base temperature to a sharply defined optimum temperature, beyond which the rate decreased linearly with temperature, reaching zero at the maximum temperature (Garcia-Huidobro et al. 1982).

In summary, we examined the effects of temperature on germination, average time to germination, threshold temperature, and heat units of *Festuca* cultivars to assess the genetic basis for their variability and the implications for selection and turfgrass establishment. The results of this study suggest that the optimum seed zone temperature for germination of *Festuca* cultivars is 15°C. Germination decreased as average time to germination increased. The seeding time for some *Festuca* cultivars could be varied based on expected seed zone temperatures for particular locations. Results of this study should be interpreted with caution, but they suggest that selec-

tion of cultivars based on anticipated seed zone temperatures will provide rapid germination and may lead to improved establishment on poorly managed sandy soils in cold climates.

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